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Comparative study of sustainability of the electrical power industry in Mexico and its northern border region

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ABSTRACT

The concept of sustainable development with three-dimensional formula was used to compare the sustainability of the electricity industry in Mexico and its northern border. Energy indicators for economic, social, and environmental dimensions were applied to the electricity industry between 1993 and 2006. According to the resulting indicators there was no balance between the dimensions. The environmental dimension yielded the least sustainable one, whereas the social dimension yielded the most sustainable indicator both in Mexico and in its northern border. The economic dimension presented greater differences in the indicators between Mexico and its northern border. The global indicator showed that sustainability in Mexico's northern border is higher than it is in Mexico. Energy policies must be applied to increase the sustainability of most indicators, to achieve a balance between the dimensions and to obtain progress toward sustainable development electrical power.

Contents

1. Introduction

In Mexico's history the electricity industry has been very important as an integral part of the country's development. The electricity industry underwent a long and difficult process of nationalization starting in 1928, with the Electrical National Code that declared the electricity industry as a public utility. This difficult process continued with the creation of the Federal Commission of Electricity in August of 1937 and the ending of the policy of nationalization in 1960. In 1992, the Law of the Public Service of Electrical Energy (LPSEE) was modified due to a reinterpretation of the concept of electrical public service. Consequently the public electrical industry of Mexico has undergone changes as a result of the participation of independent producers of electricity (IPE) for over a decade, necessitating an analysis of the situation. However the northern border

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states of Mexico, like its electrical sector, have had a very important role in Mexican history [1–7].

The U.S.–Mexico transborder region is the central piece of a binational system based on strong social, economic, and environmental connections. It is also the continental gateway for the emerging North American economic area encompassing Canada, Mexico and the United States. Extending for more than 3141 km, the U.S.–Mexico international boundary joins four U.S. and six Mexican states that together make up a territory of 2,678,569 km^2. The region is home to 83 million people, shelters the activity of hundreds of thousands of business, and is the setting for unique waterways and ecosystems. In both Mexico and the United States, border-state GDPs in 2006 were equivalent to approximately one-fourth of total national GDP (25% in Mexico, 23.7% in the United States). Combined border-state GDPs in 2006 were approximately US$3.3 trillion. Only two nations in the world, Japan and the United States, exceed this amount. The combined border states' GDP is also greater than the GDPs of Germany, France, and the United Kingdom, and 25% greater than China's [8].

On the other hand, Chapter 40 of Program 21 (P21) of the 1992 Río Summit, has necessitated the worldwide establishment, promotion, and use of sustainable development indicators as basic tools for decision making at all levels [9]. Construction and implementation of sustainable development indicators have passed through several stages. Experts (i.e., statisticians, analysts, politicians, and university faculty in departments of energy and environment) from several agencies developed energy indicators for domestic use and monitored the effects of energy policies across economic, social, and environmental dimensions of sustainable development [10,11]. The Latin American Organization of Energy (OLADE), Economic Commission for Latin America (CEPAL), and German Development Cooperation (GTZ) formulated a set of indicators to evaluate the sustainable development of the energy sector in Latin America and the Caribbean [18,19]. Similarly, International Center for Tropical Agriculture (CIAT), World Bank (WB), United Nations Environment Programme (NEP), and Interamerican Development Bank (IDB) developed indicators for Central America's energy sector [20]. These indicators have been applied by different geographical regions and countries to evaluate the impact of energy policies, including: Brazil, Cuba, Mexico and the Baltic States [12–17].

However, the sustainability of the electricity industry has experienced different approaches in the assessment of its economic, social and environmental impacts. Studies on such assessment methodologies, as developed by Kim [21], have focused on both theoretical and methodological backgrounds, critical reviews of specific studies, discussions of their results, and implications for future environmental policies and further research. Anderson [22] proposed that the backcast embrace wider environmental and social responsibilities through a more circumspect appreciation of the current knowledge and hence a more flexible and responsive policy agenda. Karger and Wilfried [23] investigated the advantages and disadvantages of decentralized electricity generation regarding the overall concept of sustainable development, and they agreed that technical and economic boundary conditions are of major importance in this field, though the security of the supply of electricity is still a matter of controversy. Regarding the application of sustainable indicators, Albrecht [24] proposed that economic systems may be considered as special ecosystems; being they serve as key indicators for energy in ecosystems because the most valuable kind of energy used in the economic systems of industrialized countries is electricity. A linear relationship between the growth pattern of electricity consumption and its relation to the gross domestic product has been found. The author's aim was to present this relationship and to initiate a discussion about its reason as well as its interpretation. Another study of energy indicators involved the analysis of convergences in the electricity intensity in sample of International Energy Agency (IEA) countries. The results indicated that convergence varies by the type of electricity used, resulting in a grouping of countries [25]. Cancino [26] researched Mexico's electricity sector and its contribution to the use of renewable energy sources, while Navarro [27] made a comparative study of the sustainable development of Mexico's electricity industry in the State of Sonora.

This paper compares the sustainable development of the electricity industry in Mexico and in the states of the northern border of Mexico from 1993 to 2006, in the context of the Mexican law reforms in the electricity industry and the signature of the North American Free Trade Agreement (NAFTA). The border between Mexico and United States was selected because of the evident regional integration processes and their influences on the development of both countries [4–7]. Another purpose of this study was to analyze the electricity industry considering the economic, social and environmental dimensions of development, a theme supported by the concept of sustainable development generated since the1992 Río Summit [9].

2. Methodology

For a quantitative evaluation of the sustainable development of the electricity industry in Mexico and in Mexico's northern border, indicators of energy sustainability were selected and adapted on the basis of the experience of international agencies that have worked in the construction of such indicators [10,18–27]. The data for the construction and normalization of the indicators were obtained from the CFE, Geography and Statistics National Institute (INEGI following the Spanish acronym), Energy Regulatory Commission (CRE, following the Spanish acronym) and Technical and Professional Association in Energy Applications (ATPAE, following the Spanish acronym) [29–33]. Three indicators were constructed along economic and environmental dimensions, as well as two indicators along the social dimension. They were applied to the electricity industry in Mexico and in its northern border. The indicators of the border were obtained by the average of the states' values of the northern border of Mexico.

Indicators were normalized to allow comparisons between the parameters and to determine a sustainability standard that would allow a quantitative assessment of sustainability of the electricity industry in Mexico and its northern border. The normalization criteria were based on the type of indicator. The resulting indicators were presented in radial graphics, which enables one to observe the three dimensions as a whole at a specific time (1993 and 2006). It also produced time-series graphs illustrating the evolution of these indicators over a period of time (1993–2006). A global indicator was also produced, as shown by the area of polygons in the radial graphics. The following are the definitions of the indicators and their respective normalization (Table 1).

2.1. Economic dimension

Self-sufficiency and power consumption, as well as the electrical industry's contribution to the generation of wealth from one region, comprise the indicators of the economic dimension.

2.1.1. Electrical autarky (AK)

Defined by a ratio of the electricity produced and consumed (electricity production/electricity consumption). Indicates self-sufficient, if is able to meet its own electricity generation. The normalization of the electrical autarky was linear: 0 = 0, 1 = 1.

Table 1
Indicators of sustainable energy development for the electricity industry.

Dimension	Indicator	Definition	Normalization
Economic	Electrical autarky	Electricity production/electricity consumption	0 = 0 1 = 1
	Electrical productivity	GDP/electricity consumption	1 ≥ 9331.32$/kWh
	Electrical robustness	Electricity product/GDP	1 ≥ 49.46%
Social	Electricity coverage	Percentage of favored inhabitants	0 = 0% 1 = 100%
	Electricity consumption per capita	Electricity consumption/inhabitant	1 ≥ 4000 kWhpc
Environmental	Carbon dioxide emissions	kg of carbon dioxide emissions during power generation per annum	0 ≥ 1179.33 kg/MWh 1 ≤ 372.98 kg/MWh
	Nitrogen oxide emissions	kg of nitrogen oxides emissions during power generation per annum	0 ≥ 6.112 kg/MWh
	Use of renewable energies	Percentage of electricity generation with renewable primary sources	0 = 0% 1 = 50%

2.1.2. Electrical robustness (ROB)

Defined by the index obtained by comparing electricity production and the gross domestic product (electricity production/GDP). The average value of the states along the southern border of the U.S., corresponding to 9331.32 $/kWh in 2006 [28], was used as a reference to normalize the electrical robustness.

2.1.3. Electrical productivity (PROD)

The ratio of the regional economic output and the consumption of power in a specific region (GDP per capita/electricity consumption). The average value of the states along the southern border of the U.S., corresponding to 49.55% in 2006 [28], was used as a reference to normalize the electrical productivity.

2.2. Social dimension

This dimension relates the electric sector's contribution to societal development, as analyzed by electricity coverage and per capita electricity consumption, thereby following the general population's access to services and the average per capita distribution.

2.2.1. Electrical coverage (COB)

The percentage of the inhabitants that have access to electricity and welfare by having this basic service, which is essential for a good quality of life. The normalization to electrical coverage was 0 = 0%; 1 = 100%.

2.2.2. Electrical consumption per capita (ECpc)

The ratio of total electricity consumption and the number of inhabitants, which provides an overview of the general distribution of power consumption without considering the economic differences of populations. The reference used to normalize the electrical consumption per capita (ECpc) was the UN recommendation of 4000 kWh per capita.

2.3. Environmental dimension

The environmental dimension provides insight into the impact on the atmosphere of power plants (≈70% of Mexico's total electrical production) due to the emissions of carbon dioxide (CO_2), major greenhouse gases, and nitrogen oxides (NO_x), one of the most toxic and reactive gases in the air and a part of the composition of photochemical smog [34].

The use renewable energy sources provides an overview of energy sources contributing to the diversification of primary energy sources, and avoided emissions of gases from burning fossil fuels in electricity production.

2.3.1. Use of renewable energies (URNV)

The ratio of the total energy produced and the amount of energy produced using renewable energy (energy production/energy production using renewable energy). Provides information on the contribution of renewable energy sources to the total electrical energy produced. To normalize the use of renewable energies (URNV) the following criteria were used: [0 = 0%; 1 = 50%].

2.3.2. Carbon dioxide emissions (CO_2E)

The ratio of 1 kg of CO_2 emitted per 1 MWh of electricity generated by thermal facilities. The CO_2E were calculated by data of electricity generated, and by emission factors which were obtained from data of ATPAE. In 2002, researchers of ATPAE [33] calculated the atmospheric emissions of power plants of CFE, which enables one to obtain the emission factors by fuel thermoelectric technology. To normalize, the interval [372.98–1179.33 kg CO_2/MWh] was provided by the natural gas and coal technologies because they are currently the best (natural gas) and the worst (coal) fuel thermoelectric technologies.

2.3.3. NO_x emissions (NO_xE)

The ratio of 1 kg of NO_x emitted per 1 MWh of electricity generated by thermal facilities. To normalize NO_xE, the interval [0.795–6.112 kg NO_x/MWh] was provided by the natural gas and coal technologies because they are currently the best (natural gas) and worst fuel thermoelectric technologies (coal).

3. Resulting indicators

The results are presented in radial charts first to show the values of the indicators and the balance between the dimensions in specific time periods. Subsequently time series graphs are presented to portray trends in the evolution of the indicators.

The radial graphs allow one to evaluate, define and compare the different levels of sustainable development. When using radial graphs it is important to note the form, position and size of the resulting polygonal area, with the idea that sustainability is most optimal when the area covers the whole graph. In the case with Mexico (Fig. 1) and its northern border (Fig. 2) the graph does not show a balance between the dimensions in any of the years evaluated, as the values are higher in 2006 than in 1993 in both cases. The size and position associated with Mexico's northern border (MNB) show better levels of sustainability than the country as a whole.

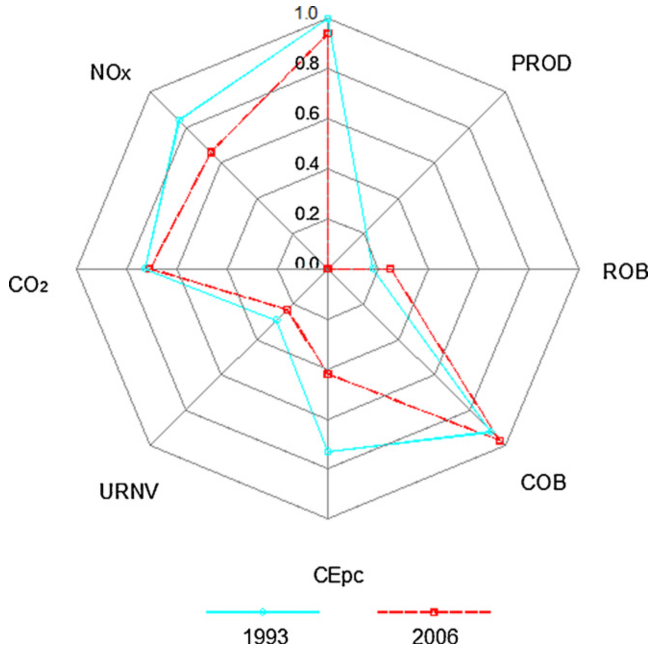

Fig. 1. Mexico's global sustainable radial graph.

However Mexico is different from its northern border in the following ways: sustainability in Mexico is higher than the MNB in the environmental dimension, size increases in the social dimension, and in the economic dimension productivity is lower in Mexico than in the border; instead the robustness is minor in the northern border than in Mexico. In terms of autarky the values were very close to unity in the country over two years. The values for the border in 1993 were larger than those in 2006 but did not reach the levels of Mexico (Figs. 1 and 2).

Productivity is positively correlated with a higher degree of sustainability. This does not necessarily guarantee energy efficiency, however. One needs to take into account the structural effects, such as the weight of the other industries and sectors in the total

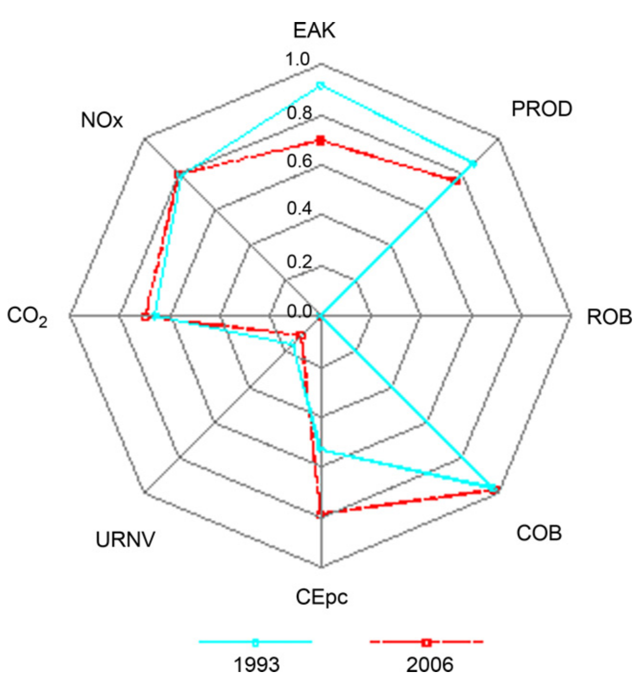

Fig. 2. Mexico's northern border global sustainable radial graph.

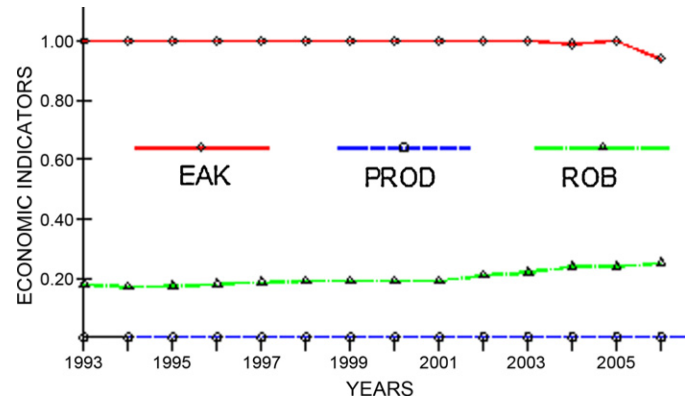

Fig. 3. Economic indicators of Mexico.

accounting of the economy, especially because the border regions place much weight on the maquiladora industry and yet have better values than Mexico. The border regions have a great weight of the maquiladora industry and yet have better values than Mexico. Robustness showed higher levels in Mexico than in its northern border in 1993 and in 2006 (Figs. 1 and 2).

Two of the three indicators of economic size in the northern border of Mexico showed the country's highest levels, although they decreased slightly in 2006. Regarding the social dimension, both indicators showed better performance in border region as a whole, as they increased their values better than Mexico in 2006. Regarding environmental indicator CO_2 emissions were very similar in the two regions for both years. The NO_x emissions were also similar in both regions, although low levels were recorded in Mexico in 2006. Regarding the use of renewable energy sources, the two regions had almost identical values in the two years. The global indicator for Mexico was 26.8% in 1993 and 25.2% in 2006, whereas the equivalent for MNB was 34.3% in 1993 and 32.4% in 2006 (Figs. 1 and 2).

The trend of evolution of the economic dimension was more stable for the country of Mexico than for the northern border. The productivity was zero over the entire period for Mexico, while the MNB had a mean value of 0.8. In the social dimension the MNB has higher values (mainly in terms of ECpc), which also grew at a faster rate than they did in Mexico. The environmental dimension highlights the limited contribution of renewable energies in both regions. In the MNB the final year of measurement showed lower renewable energy use than in earlier years (Figs. 3–8).

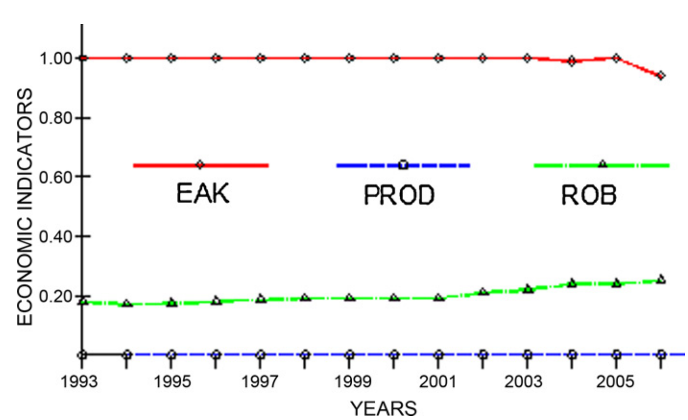

Fig. 4. Mexico's northern border economic indicators.

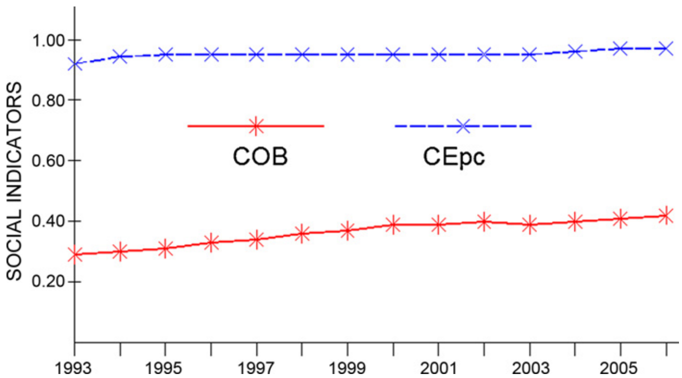

Fig. 5. Social indicators of Mexico.

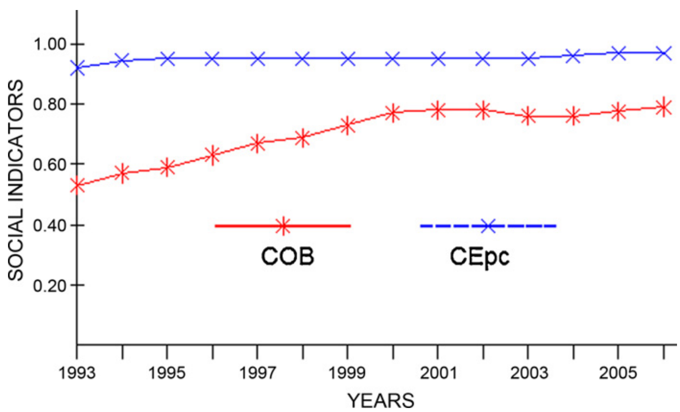

Fig. 6. Mexico's northern border social indicators.

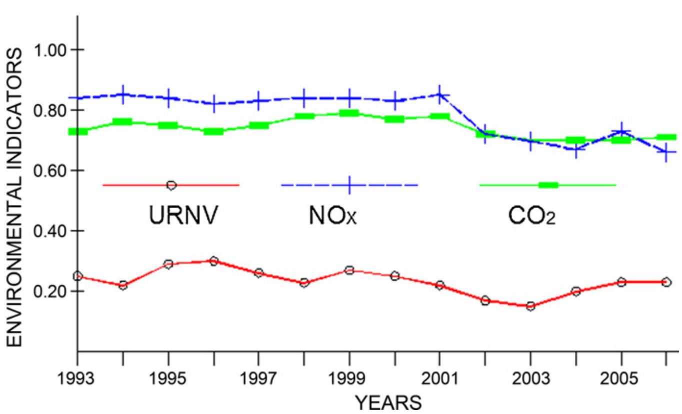

Fig. 7. Environmental indicators of Mexico.

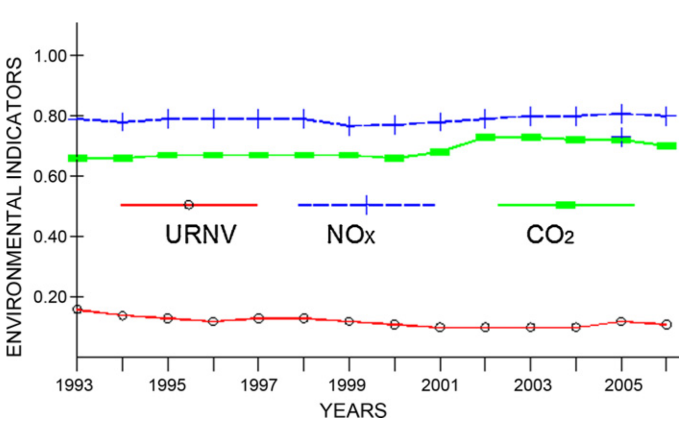

Fig. 8. Mexico's northern border environmental indicators.

4. Conclusions

By evaluating the development of the electricity industry from the point of view of a single dimension, we obtained partial results. However, if by introducing at least the social, economic and environmental aspects, we can get a more objective assessment for electricity industry development. With normalization of the indicators, it is possible define the standards of sustainability, compare between different dimensions of development and measure progress toward sustainable development.

The set of indicators applied to Mexico and to its northern border show differences in sustainable development between two regions, with the global indicator having the most impact in the MNB. In general, the dimensions present an almost constant behavior in the entire period studied. In the MNB, the economic dimension (e.g. autarky and productivity) showed decreased sustainability whereas the social dimension (e.g. electrical consumption per capita) showed increased sustainability at the end of the period studied.

The increasing trend in the electrical consumption per capita in the MNB is made possible by its high electrical coverage, which also explains the air conditioning found in the houses and buildings. The use of renewable energy sources is an indicator that debilitates the environmental dimension in the northern border of Mexico in significantly larger measure than in the country itself; nevertheless, the emissions are decreased in the border.

It is necessary to promote energy policies that can balance sustainability levels of dimensions studied, especially by encouraging the use of primary sources renewable energy. Since the sub-region formed by Baja California, Sonora (Desert of Altar), Chihuahua and Coahuila (Desert of Samalayuca, the largest desert in Mexico) is located in the world's biggest solar radiation strip, it has great potential for generating solar energy that can reach values of up to 5–6 $kWh/m^2/day$ (NREL [35]). There is also great potential for wind energy in the Sierra Madre Occidental area, as well as the coasts along the Gulf of Mexico and the Atlantic Ocean. Promoting these policies would bring benefits to all three-dimensional developments because doing so would enable Mexico's northern border region to have self-sufficient supplies of electricity using renewable and clean resources.

On the other hand, it is necessary to implement and create citizen participation forums or institutions outside the scope of the federal government regarding the policy development of the electricity industry. The Mexican State, its institutions and its society must think and provide elements for the integrating of globalization with a future vision to overcome under-development and to join the world in the best way possible without compromising the progress made throughout its history. The electricity industry can play a strategic role in this effort to support the economy.

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